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Europäisches Patentamt
European Patent Office
Office européen des brevets

11 Publication number:

**0 269 300
A1**

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EUROPEAN PATENT APPLICATION

21 Application number: 87309892.5

51 Int. Cl.4: G01F 1/708

22 Date of filing: 09.11.87

30 Priority: 24.11.86 GB 8628055

43 Date of publication of application:
01.06.88 Bulletin 88/22

84 Designated Contracting States:
DE ES FR GR IT NL SE

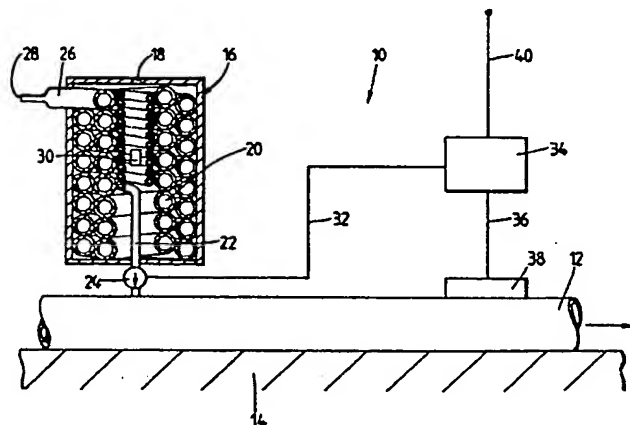
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54 Flow measurement

57 A method and an apparatus are provided for measuring the flow rate of a fluid in a duct, for example in an under-sea crude oil pipeline (12), in which samples of a radioactive tracer are injected, at intervals, into the duct and the passage of the samples of tracer detected by a scintillator (38). The tracer is generated by irradiating a large volume (20) of a liquid obtained from the environment of the duct with a neutron source (30), so that the sample has been irradiated for a prolonged period prior to injection.



EP 0 269 300 A1

Flow Measurement

This invention relates to a method and an apparatus for measuring the flow of a fluid in a duct, and particularly though not exclusively for measuring the flow of liquid in a sub-sea pipeline.

According to the present invention there is provided a method for measuring the flow of a fluid in a duct, the method comprising, storing test fluid in a container adjacent to the duct, irradiating the test fluid in the container with neutrons so as to generate atoms of a radioactive nuclide in the test fluid, injecting at intervals a sample of the irradiated test fluid into the duct, detecting, at a location spaced apart along the duct from the location at which the injection takes place, radiation emitted by the radioactive atoms, and determining, from the elapsed time between the injection of the test fluid and the detection of the radiation, the flow of the fluid.

The invention also provides an apparatus for measuring the flow of a fluid in a duct, the apparatus comprising a container adjacent to the duct for storing test fluid, a neutron source arranged to irradiate the test fluid in the container so as to generate atoms of a radioactive nuclide, means for injecting a sample of the test fluid into the duct at intervals, means for detecting radiation emitted by the radioactive atoms, the detecting means being spaced apart along the duct from the injecting means, and means for determining, from the elapsed time between the injection of the test fluid and the detection of the radiation, the flow of the liquid.

Preferably the test fluid is obtained from an environment near the duct. An advantage accruing from use of a test fluid obtained from the environment of the duct is that the apparatus can operate for a long period of time without any need for servicing; the period of operation is not limited by the storage capacity of the container. It is therefore suited to use in remote or hostile locations such as on the sea bed.

The invention is especially suited to measuring flow in under-sea pipelines carrying oil, for example from an oil well. In such a situation the test fluid may be obtained from the sea, and be sea water. This typically contains sodium ions at a concentration of about 10 g/litre. As a consequence of neutron irradiation, sodium-24 nuclides are created. These decay with emission of beta and gamma radiation and with a half-life of 14.8 hours.

The invention will now be further described, by way of example only, and with reference to the accompanying drawing which shows a diagrammatic view, partly in section, of a flow measuring apparatus 10, arranged to measure the flow in a

crude oil pipeline 12 lying on the sea bed 14. The apparatus 10 is entirely surrounded by and immersed in sea water.

The apparatus 10 includes an irradiation chamber 16, cylindrical in shape, made of steel coated with an anticorrosion plastic coating, and with a small vent hole 18 in its top. The chamber 16 encloses a copper tube 20 wound into a number of helically wound layers; the portion of the tube 20 forming the innermost layer is of narrower diameter than the remainder of the tube 20. An end portion 22 of the tube 20 extends from the innermost layer of the winding out of the base of the chamber 16 and is connected via a constant volume, high pressure, injection pump 24 to the bore of the pipeline 12. The other end portion 26 of the tube 20 projects from the chamber 16, tapering to a narrower diameter, and being open at its end 28. Since the apparatus 10 is immersed in sea water, sea water fills the chamber 16 and the entire length of the tube 20; the volume of sea water in the tube 20 is about 50 litres. At the centre of the irradiation chamber 16 is a 100 microgram californium-252 neutron source 30 providing 2.3×10^8 neutrons/sec. These are moderated by the sea water so the sea water in the tube 20 is subjected to irradiation by thermal neutrons. At a distance of 40 mm from the source 30 the flux is about 10^6 thermal neutrons per cm² per second.

The pump 24 is connected by a power supply cable 32 to a microprocessor unit 34. The unit 34 is connected by a cable 36 to a sodium iodide scintillator 38 mounted on the wall of the pipeline 12 at a distance in the flow direction from the point at which the injection pump 24 is connected to the pipeline 12 such that the oil/water in the pipeline 12 takes about 10 seconds to travel that distance. The scintillator 38 itself is of such a length that the oil/water in the pipeline 12 flows past it in about a tenth of a second. The unit 34 is also connected by a power-supply and data transmission cable 40 to a power source (not shown) which may be remote from the apparatus 10.

In operation of the apparatus 10 the sea water filling the tube 20 is constantly irradiated by thermal neutrons from the source 30, so that sodium-24 nuclides are generated from the sodium naturally present in the sea water. Once every fifteen minutes the pump 24 is energised to inject 50 millilitres of this irradiated sea water into the pipeline 12. After about ten seconds this injected sample of sea water will pass the scintillator 38 which detects the gamma radiation emitted as a result of the decay of the sodium-24 nuclides. From the time interval between energising the pump 24 and

the detection of the gamma rays by the scintillator 38, the flow velocity of the contents of the pipeline 12 are calculated by the microprocessor 34, this data being transmitted along the cable 40.

Since the end 28 of the tube 20 is open, the tube 20 remains full of sea water at all times, and the sea water flows along the tube 20 slowly (at a rate corresponding to 50 ml per 15 minutes) taking just over ten days to flow the length of the tube 20. The long helical winding and the narrow end portion 26 minimise diffusion of irradiated sea water back out of the open end 28.

Assuming for simplicity that the neutron flux is uniform throughout the length of the tube 20, and considering a small volume of the sea water in the tube 20 which at a time t includes N_S stable atoms and N_R radioactive atoms (whose sum is N_T). Then:

$$dN_R = FN_S dt - c N_R dt$$

where F is a constant depending on the neutron flux and the cross-section for production of the radioactive nuclei, and where c is the decay constant for the radioactive nuclei. Consequently, after irradiation of the sea water for a time t_r :

$$N_R = (F N_T/c)(1 - e^{-ct_r})$$

is the number of radioactive atoms present. (This assumes that only a small proportion of the atoms present become radioactive).

This small volume of seawater is then injected into the pipeline 12, and passes along the pipeline 12 past the scintillator 38. If the transit time taken for it to reach the scintillator 38 is t_t , and the time during which gamma rays from the irradiated sea water are counted is t_c , then the number of gamma rays detected will be:

$$n = (KFN_T/c) - (1 - e^{-ct_c}) e^{-ct_t} (1 - e^{-ct_r})$$

where K is a constant. Since in practice the counting time will be much shorter than the transit time and the irradiation time, and will be much less than the half-life of the radioactive nuclei (i.e. since ct_c is much less than one) this can be written as:

$$n KFN_T t_c e^{-ct_t} (1 - e^{-ct_r})$$

It is evident that the number of gamma rays detected depends in general upon the decay constant c . For any given values of irradiation time and transit time there is an optimum value of c which gives the largest number of detected gamma rays. This corresponds to an optimum half-life T lying between the values of the transit time and the irradiation time, and given by:

$$T = t_r \log 2 / \log((t_r + t_t)/t_t)$$

For example in the apparatus 10 the sample of sea water is irradiated for ten days before injection, and the transit time is about 10 seconds. For these values, the optimum half-life of the radioactive nuclei is:

$$T = 52\,700 \text{ sec} = 14.6 \text{ hours}$$

This is close to the half-life of sodium-24, which is 14.8 hours.

However, as long as the irradiation time is several half-lives, then the equilibrium concentration of the radioactive nuclide will be achieved; and as long as the transit time is a small fraction of the half-life, then the activity will not significantly decrease during transit. Thus the values of the irradiation time, half-life, and transit time are not critical. Under such circumstances the decay constant c does not affect the number of gamma rays detected, which is given by:

$$n = KFN_T t_c$$

and hence the factors which determine the number of gamma rays detected are the parameters F , relating to the neutron flux to which the test fluid is subjected, and to the cross-section for the activation reaction, and N_T relating to the concentration in the test fluid of the nuclides which can undergo the activation reaction, and to the volume of the injected sample. In the present case, the cross-section of sodium is 0.54 barns; and as mentioned earlier the concentration of sodium ions typically 10g/litre.

If any other gamma-emitting nuclides are also generated (for example a chlorine isotope) this will increase the number of gamma rays detected. It will be appreciated that the dimensions of the tube 20 may differ from those described, as too may the volume of the injected sample. The injected volume is chosen to ensure that passage of the injected sample can be reliably sensed by the scintillator 38, i.e. that sufficient gamma counts are received; and that the gamma counts received form a sharp peak, i.e. that the injected test fluid occupies only a short length within the pipeline 12. In the apparatus 10 it will be appreciated that the detected gamma count can be increased by increasing the injected volume of test fluid; although this reduces the irradiation time, and hence the activity of the test fluid, this is more than made up for by the increased volume. However the injected volume must be small in comparison with the volume per unit length of the pipeline 12, and the time taken for the injection must be short in comparison with the transit time.

Claims

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1. A method for measuring the flow of a fluid in a duct (12), the method being characterised by storing test fluid in a container (20) adjacent to the duct, irradiating the test fluid in the container with neutrons so as to generate atoms of a radioactive nuclide in the test fluid, injecting at intervals a sample of the irradiated test fluid into the duct, (12) detecting, at a location (38) spaced apart along the duct from the location (24) at which the injection takes place, radiation emitted by the radioactive atoms, and determining, from the elapsed time between the injection of the test fluid and the detection of the radiation, the flow of the fluid.

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2. A method as claimed in Claim 1 wherein the test fluid is obtained from an environment near the duct (12).

3. A method as claimed in Claim 1 or Claim 2 wherein the test fluid is irradiated for a time more than the half-life of the radioactive nuclide, and the location (38) at which detection is performed is at such a separation from the location (24) at which the injection takes place that the elapsed time is much less than the half-life of the radioactive nuclide.

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4. An apparatus (10) for measuring the flow of a fluid in a duct (12), characterised in that the apparatus comprises a container (16) adjacent to the duct (12) for storing test fluid, a neutron source (30) arranged to irradiate the test fluid in the container (16) so as to generate atoms of a radioactive nuclide, means (24) for injecting a sample of the test fluid into the duct (12) at intervals, means (38) for detecting radiation emitted by the radioactive atoms, the detecting means (38) being spaced apart along the duct (12) from the injecting means (24), and means (34) for determining, from the elapsed time between the injection of the test fluid and the detection of the radiation, the flow of the liquid.

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5. An apparatus as claimed in Claim 4 including means (28) for obtaining the test fluid from an environment near the duct.

6. An apparatus as claimed in Claim 4 or Claim 5 wherein the container (16) incorporates a tube (20) communicating at one end (22) with the injection means (24) and at the other end (28) with a source of the test fluid, the tube extending adjacent to the neutron source (30).

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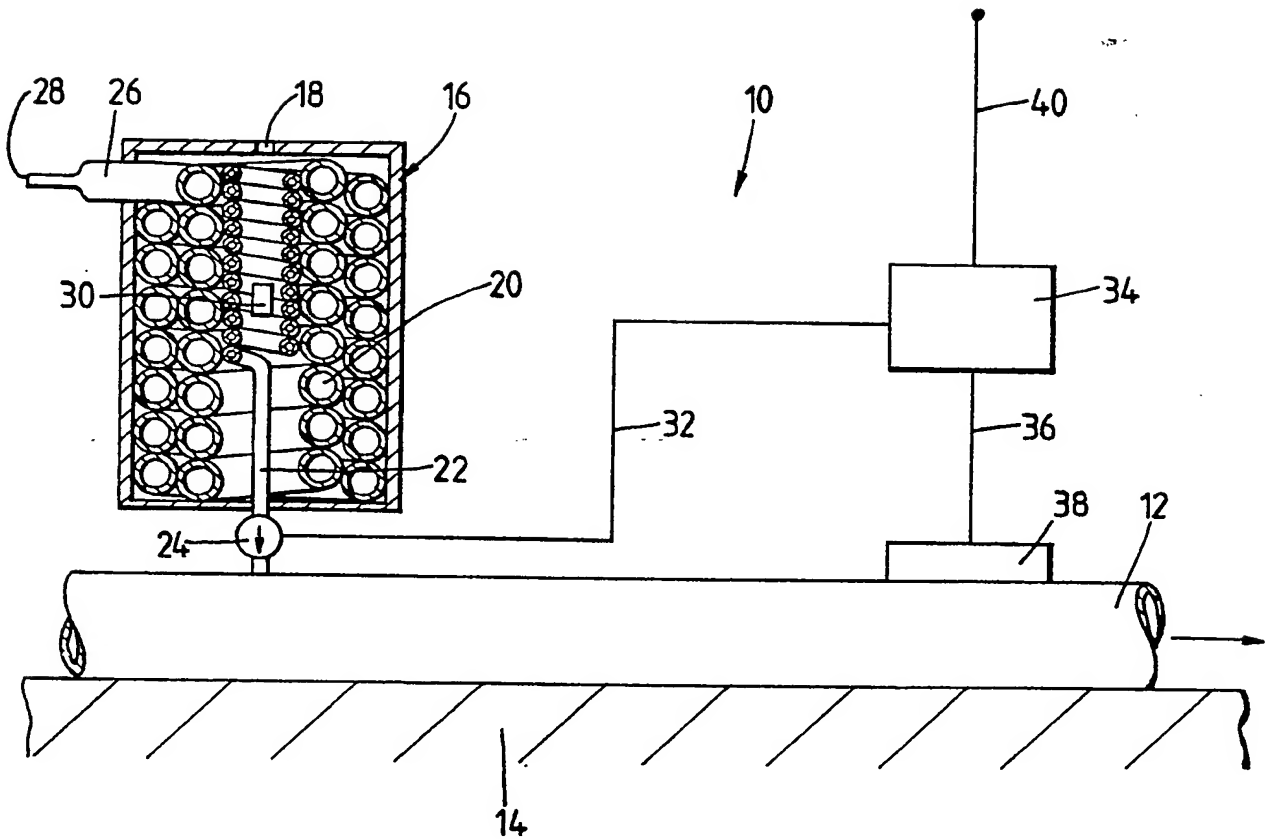
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7. An apparatus as claimed in Claim 6 wherein the tube (20) extends along at least one helical path around the neutron source.

8. An apparatus as claimed in Claim 6 or Claim 7 wherein the tube (20) is of such dimensions in relation to the rate of injection of the test fluid, that

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each sample of test fluid will be irradiated for a time longer than the half-life of the radioactive nuclide.





DOCUMENTS CONSIDERED TO BE RELEVANT			EP 87309892.5
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
Y	GB - A - 862 891 (CALIFORNIA) * Fig. 3; page 7, lines 35-92 * --	1,2,4,5	G 01 F 1/708
Y	GB - A - 2 036 957 (TEXACO) * Abstract * --	1,2,4,5	
A	US - A - 2 841 713 (HOWARD) * Fig. 1,2,6; column 3, line 69 - column 7, line 39 * -----	1,3,4	
The present search report has been drawn up for all claims			
Place of search VIENNA		Date of completion of the search 16-02-1988	TECHNICAL FIELDS SEARCHED (Int. Cl. 4) G 01 F 1/00
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	